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DRAWINGS ATTACHED

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(71) We, E. I. Du Pont de Nemours and Company, a Corporation organized and existing under the laws of the State of Delaware, United States of America, of Wilmington 98, State of Delaware, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a process and apparatus for preparing strong nonwoven fabrics.

During processing in carpet mills, tufted primary carpet backings are subjected to considerable longitudinal stress which may lengthen the carpet in the direction of stress and cause a narrowing of the tufted backing in the direction transverse thereto. Such dimensional changes are highly undesirable since they result in an undesirable change in tufting pattern and nonuniform carpet width.

The product prepared by the process of the present invention when properly bonded is exceptionally resistant to this excessive dimensional change and is thus suitable for use as a primary carpet backing.

Thus the present invention provides a process for preparing directional nonwoven webs of uniform basis weight which when bonded have high resistance to deformation coupled with high tear strength, and are especially suited for backing for tufted carpets which process involves deflection of filament-containing fluid streams.

Deflection of filament-containing fluid streams with secondary fluid stream is disclosed in U.S. Patent Specification No. 2,863,493. Australian Patent Specification No. 242,895 discloses the preparation of continuous filament glass fiber mats by mechanical deflection of a fluid stream containing continuous glass fibers. However, neither of these specifications give any indication of the filament alignment in the final product nor do they teach one skilled in the art the steps and conditions required in the present process.

The present invention provides a process for preparing a unitary directional nonwoven web by forming a plurality of primary gas streams each forwarding a plurality of electrostatically charged continuous filaments, preferably filaments electrostatically charged to at least 30,000 ESU/m^2, and collecting the separated filaments from the gas streams on a continuously moving receiving surface, in which process at least one of the gas streams is pneumatically oscillated so that its filaments traverse the receiving surface at a substantially constant deflection amplitude (as hereinafter defined) and at a substantially constant deflection velocity (as hereinafter defined) which is at least one-third the velocity of these filaments along their length, as measured immediately before oscillation.

Preferably, the oscillation of at least one of the gas streams is in a direction at an angle of 45 to 90°, especially 90° to the direction of travel of the receiving surface.

In a preferred embodiment a plurality of primary gas streams is oscillated simultaneously in substantially the same direction and the group of filaments collected from each such gas stream contacts (i.e. overlaps or abuts) those collected from another primary gas stream or streams. Preferably the contact occurs at least at the points in the groups of collected filaments where the filaments reverse direction.

In a particularly preferred embodiment there is simultaneously a first and second such plurality of primary gas streams forwarding filaments, the direction in which the first plurality is oscillated being substantially at right angles to the direction in which the second plurality is oscillated. In particular one of the directions of oscillation

is in the direction of travel of the receiving surface and the other is at right angles to this. Preferably the group of filaments collected from each primary gas stream of the plurality being oscillated at right angles to the direction of travel of the receiving surface contacts the or each group of filaments collected from the or each adjacent primary gas stream of this plurality at least at the points in the groups where the filaments reverse direction, and the group of filaments collected from each primary gas stream of the plurality being oscillated in the direction of travel of the receiving surface contact the or each group of filaments collected from the or each adjacent primary gas stream of this second plurality at least along the edges of the groups of filaments.

For optimum uniformity of product the gas streams in each plurality of primary gas streams should be parallel to each other immediately before oscillation and are oscillated in phase with each other. Preferably the plurality of filaments forwarded by at least one of the gas streams is in the form of a ribbon of filaments.

Preferably, the oscillations of the primary stream are effected by periodically impinging thereon at least one secondary stream of gas whose forward direction makes an angle of 60—90° to the forward direction of the primary gas stream such that the filaments forwarded by the primary gas stream are deflected by not more than 45°.

Most preferably two secondary gas streams alternately impinge on opposite sides of the primary gas stream thereby deflecting said primary gas stream alternately in opposite directions perpendicular to the direction of the primary gas stream.

The filaments from the primary gas stream are collected on the receiving surface in groups oriented in the direction of deflection. Preferably adjacent groups of filaments which have been deflected in this manner in the cross machine direction overlap and/or abut at the points in the groups of collected filaments where the filament direction is reversed. Adjacent groups of filaments which have been deflected in this manner in the machine direction preferably abut and/or overlap along the sides of these collected groups of filaments.

The deflection velocity should preferably be at least 2.5X the velocity of the receiving surface.

The present invention also provides an apparatus suitable for carrying out the process of this invention comprising:

(a) a plurality of filament-forwarding devices, each device being adapted to forward a plurality of electrostatically charged filaments in a primary gas stream, at least one of the devices containing a passageway whose principal axis is a straight line and whose cross-section perpendicular to this axis is a rectangle, down which passageway the gas stream and filaments pass,

(b) a means at the bottom of said passageway for pneumatically oscillating the primary gas stream emanating from said passageway, the means comprising at least one slot, preferably 0.005—0.080 inch wide, whose length is parallel to the length of said rectangle, which slot is connected to a source of gas under pressure, the means being adapted to supply pulses of the gas from a chamber through the slot as a secondary gas stream to impinge on the primary gas stream emanating from said passageway such that the forward direction of the secondary gas stream makes an angle of 60—90°, preferably 70°, to the forward direction of the primary gas stream,

(c) a continuously moving receiving surface adapted to collect the separated filaments from the gas streams.

Preferably, in means (b) there is a pair of said slots aligned on opposite sides of said passageway such that the pulses of secondary gas supplied through the slots impinge on the principal axis of the passageway at the same point, both slots being connected to the same source of gas under pressure *via* a valve adapted to supply pulses of the gas alternately to the slots.

Most preferably, in means (b) the slot is connected to the source of gas under pressure *via* a valve and a conduit from the valve to the chamber, said valve comprising

(a) a valve body having a cylindrical bore defining a peripheral wall, an inlet at one end adapted to connect to the source of gas and at least one outlet in the peripheral wall connected to the conduit, and

(b) a driven cylindrical rotor disposed in wiping contact in the bore, there being a cavity in said rotor in communication with the inlet and a peripheral rotor port in communication with the cavity and adapted for registry with the outlet, thereby providing periodic communication between the outlet and the inlet during rotation of the rotor; the port during registry with the outlet, providing a change in the open area, Z, of the outlet which varies with time, t, such that Z is proportional to t^n, where n is 1 or greater (and is preferably 2) during the period of the beginning of registry to full registry of the port and outlet, the valve being sized to provide flow at sonic velocity through the outlet at all degrees of correspondence of the outlet and port during registry, and the conduit being sized to provide flow at less than sonic velocity at all degrees of openness of the valve and such that the pressure in the chamber increases

and decreases in a manner substantially directly proportional to time. In general, the apices of the rotor port are symmetrically aligned with respect to the rotor axis. In a preferred embodiment between the rotor and the peripheral wall of the valve body there is a bearing sleeve coaxial with the bore of the valve body and having a port in alignment with the or each outlet in the peripheral wall. Preferably the rotor port is in the shape of a square, diamond, triangular or hypocycloid.

In the process of the present invention, continuous filaments are forwarded by a primary gas stream and then deflected by a secondary gas stream impinging on the primary stream. Without being bound thereby, it is believed that the actual angle through which the filaments are deflected will be determined by the kinetic energy of the primary and secondary gas streams and the angle at which the secondary gas stream impinges on the primary gas stream. Thus, in order to obtain the desired deflection amplitude, the kinetic energy of the secondary stream must be varied from substantially zero to a maximum and then back again to substantially zero (i.e. from a stream having no deflection effect to one having maximum deflection effect and back again to one having no deflection effect).

In order that the collected filaments will be uniformly deposited on the receiving surface, a substantially constant deflection velocity is required. Thus, it is necessary that the increase and decrease of the pressure of the gas in the chamber from which the secondary stream issues are directly proportional to time, thus pressure of secondary gas stream increases in a manner directly proportional to time until maximum deflection (i.e. the reversal point) is reached and then decreases in the same manner until the position of no deflection is reached. Such a time response is shown in Figure 10 of the accompanying drawings. The valve mentioned above is the preferred means for so regulating the pressure.

"Filament-forwarding device" means a device for transporting the filaments from one position to another. An air jet as shown in Figure 2 is a suitable filament-forwarding device for use in the present invention.

The "primary gas streams" are the gas streams which carry the filaments through the filament-forwarding device.

"Filament velocity" V is the velocity of a single filament along its length immediately before oscillation and can be determined by collecting filaments leaving the filament-forwarding device for a given period of time and measuring their length. The average length of filament collected per unit time is the filament velocity. Alternatively, the velocity of a filament as it enters the filament-forwarding device can be measured on a running filament and from the difference in denier, if any, between the entering and the leaving filaments, the effect of draw or relaxation in the filament forwarding device (if any should occur) can be compensated for and the velocity of the filament immediately before oscillation can be calculated in known manner.

"Machine direction" refers to the direction of travel of the receiving surface.

"Cross-machine direction" is the direction 90° to the machine direction.

"Deflection velocity" is a measure of the velocity at which the filaments traverse the receiving surface and is defined by the formula:

$$\text{Deflection velocity} = 2Af$$

where A is the deflection amplitude and f is the deflection frequency.

"Deflection amplitude" is the distance between similar points in a group of collected filaments in the direction of deflection at the two extremes of the travel (from traverse reversal to traverse reversal) which would be obtained if the receiving surface were not moving.

The "deflection frequency" is the reciprocal of the time it takes for a filament to traverse a double amplitude.

When the deflection velocity, 2Af equals the filament velocity, V and assuming constant deflection velocity, the structure would be completely composed of groups of aligned filaments. When operating at the limiting case $2Af = V$, amplitude and frequency should be adjusted so that web uniformity is maintained.

Preferably this invention is used in conjunction with a process for the preparation of nonwoven webs such as is described in British Patent Specification No. 932,482. To provide electrostatically charged filaments a corona charging device such as is described in U.S. Patent Specification No. 3,163,753, may be employed. A plurality of filament-containing gas streams may be used to prepare wide continuous nonwoven webs of substantially uniform fabric weight.

The deflected filaments loop back on themselves as they begin their movement in the opposite direction and thus the nonwoven fabric produced has strength in directions other than just in the direction of filament deflection.

The combination of constant deflection velocity and electrostatic charging of the filaments results in the laying down by the oscillating gas streams of groups of filaments of substantially uniform fabric weight and with well separated filaments providing gradually tapering edges, as is particularly

desirable when there are a plurality of oscillating gas streams. The filaments are preferably charged to at least 30,000 ESU/m², e.g. as described in British Patent Specification No. 932,482 before they are fed to the forwarding device. A constant deflection velocity may be achieved by regulation of the pressure of the secondary gas stream(s).

The deflection velocity of the filament must be substantially constant and be at least one-third of the filament velocity, i.e. the velocity of the filaments along their length, as measured immediately before oscillation. This must be so in order to ensure that the alignment of filaments in the product is sufficient to provide a product having markedly superior properties when used in primary carpet backings to that obtained with a completely random filament arrangement.

In order to prepare a primary carpet backing with a highly desirable balance of physical properties, continuous filaments of isotactic polypropylene are preferably employed.

The filaments of nonwoven webs prepared according to this invention, e.g. those of isotactic polypropylene filaments comprising highly oriented and relatively unoriented zones along the length of the filaments, may be bonded for example in the manner described in Belgian Patent Specification No. 668,406 to provide a strong, dimensionally stable, nonwoven fabric which is eminently suitable for use as a backing for tufted carpets.

The present invention is further illustrated with reference to the accompanying drawings wherein:

Figure 1 is an elevation of the apparatus of this invention which for reasons of simplicity illustrates only two deflection devices operating in the machine direction and only two in the cross-machine direction.

Figure 2 is a cross-section through a modified slot jet suitable for use as a filament forwarding device in this invention.

Figure 3 is a view of the lower end of the modified slot jet of Figure 2.

Figure 4 is a curve showing the filament alignment in the product obtained when filaments are deflected in the machine direction only when the deflection velocity is about one half the filament velocity.

Figure 5 is a curve showing the filament alignment in the product obtained when filaments are deflected in the machine direction only when the deflection velocity in a single direction is about equal to the filament velocity. In Figures 4 and 5, MD and XD denote the machine direction and the cross-machine direction respectively.

Figure 6 illustrates an apparatus which can be used to measure filament alignment in nonwoven webs.

Figure 7 is a schematic view of a rotary valve suitable for use in the production of nonwoven webs.

Figure 8 is a partially sectioned elevation of the rotary valve of Figure 7.

Figure 9 is a section view of Figure 8 taken along 9—9.

Figure 10 is a graph showing the pressure of gas in the chamber from which the secondary gas stream issues as a function of time for the preferred rotary valve apparatus of this invention thus having two secondary gas streams alternately impinging on the primary gas stream.

With reference to Figure 1, electrostatically charged continuous filaments are forwarded by means of slot jet devices 2, toward a flexible pervious belt 3, covering a suction means (not shown). As the tension on the filaments is released at the exit 4, of the slot jet device 2, the filaments are deflected alternately by opposing air streams issuing from filament deflection gaps (discharge slots) 5, 6, supplied alternately by plenums 7 and 8 and 9 and 10. Chambers 7, 8, 9 and 10 are connected through manifolds and transfer lines (not shown) to compressed air supplies governed by rotary valves having variable speed drives (not shown), that alternately provide air to the opposing plenums. In this figure, a first "bank" or row 11 of two jets is used for "machine direction" deflection and a second "bank" 12 of two jets is used for "cross-machine direction" deflection.

Referring to Figures 2 and 3, slot jet 12 has an entrance slot 13 projecting into effuser throat 15 and a substantially rectangular, filament passage 17. Plenum 19 is supplied with pressurized gas through ports 21, 23. A diffuser section 36 is attached to the outlet end 38 or jet 12 and defines a filament passage 40 of rectangular cross-section in alignment with passage 17 of the jet. The jet shown schematically in Figure 2 is similar to the slot jets described in U.S. Patent Specification No. 3,302,237 modified with a diffuser section 36. The end 39 of the diffuser 36 converges toward filament passage 40 while housing 24 is formed to present an interior surface 41 complimental to and spaced from end 39 thus forming slot 18 which is disposed toward and runs lengthwise of the passage 40. Slot 20 is formed in the same fashion and is defined by complimental surfaces 37, 43.

In operation, pressurized gas, e.g. compressed air, is supplied to a rotary valve (not shown) which is rotated at a constant speed and alternately connects conduits 32, 34 to the source of compressed air. The resulting pulses of air are fed to chambers 26, 28 where they discharge from slots 18, 20 at an angle θ to the slot 40, and impinge against filaments as they leave slot 40 de-

flecting them in alternate directions in a uniform pattern.

The deflection slots 18, 20 are arranged so that the deflecting streams impinge on the filament stream issuing from passageway 40 of the diffuser with the primary gas stream at an angle θ of from 60 to 90°; a useful compromise is to use an angle θ of 70°. At this angle aerodynamic effects caused by the shape of the bottom part of the housing 22 are minimized while still maintaining reasonable efficiency in the amount of deflection air consumed. The deflection slots 18, 20 should be sized to achieve the desired deflection at moderate chamber pressure e.g. 1 to 5 p.s.i. (.07—.35 kg/cm²). The preferred slot width is from .015 to .020 inches (.038 to .050 cm.) although slot widths of from .005 to .080 inches (.012 to .202 cm.) may be used. The length of the chambers 26, 28 and slots 18, 20 should correspond to the lengthwise dimension of the diffuser outlet 40. The exit gap *A*—(Figs. 2, 3) between the passageway end of the diffuser and housing 22 is preferably between .05 to .50 inches (.12 to 1.2 cm.).

While it is preferred that the deflection housings 22, 24 be attached to a diffuser section forming the outlet of a slot jet it is not necessary to use a diffuser section and the deflection housing may be attached directly to the outlet end of a slot jet without a diffuser as described in U.S. Patent Specification No. 3,302,237.

Of course it should be understood that the outlet end of the jet described in U.S. Patent Specification No. 3,302,237 would be modified to converge toward the passage to form with housings 22, 24, the angularly disposed slots. It is not necessary that the deflection device of this invention be positioned on both sides of the jet or diffuser outlet. A single housing 22 on one side of the jet with or without diffuser may be used.

Figure 4 shows a curve representing the filament alignment in the product, determined by the "Randometer" procedure, described hereinafter, for a bonded nonwoven web prepared by deflecting filaments, in the machine direction only, at a deflection velocity equal to 55% of the filament velocity (535 yards per min.). Increased filament alignment, substantially in the machine direction, is noted when compared to random webs.

Figure 5 shows a similar curve representing the filament alignment determined in the same manner as for Figure 4 from a similar bonded nonwoven web prepared using a deflection velocity which is about equal to the filament speed. Further increase in filament alignment, substantially in the machine direction, is noted.

Figure 6 shows a pictorial layout of an apparatus suitable for determining filament alignment in nonwoven webs. The apparatus is hereinafter referred to as a randometer.

Referring to Figure 7 electrostatically charged continuous filaments 110 are forwarded by means of a slot jet 112 toward a flexible pervious belt 114 covering a suction means (not shown). As tension on the filaments is released at the outlet end 116 of jet 112 the filaments are deflected by alternate opposing pulses of air issuing from slots 118, 120 formed between the end 116 and housings 122, 124 attached adjacent to the outlet end 116. Housings 122, 124 by means of conduits 126, 128 are connected to rotary valve 130, supplied with compressed air at inlet 132.

Referring now to Figures 8, 9 rotary valve 130 includes a valve body having a cylindrical bore 142 defining a peripheral wall 143 and an inlet 145 at one end of the body. Flanged inlet pipe 132 is connected to the inlet end 145 of the body 140 and with a supply of compressed air or other pressurized gas. Conduits 126, 128 are connected to opposed diamond shaped outlets 144, 146 respectively, in the peripheral wall 143 of valve body 140. The conduits are circular in cross-section and have a greater cross-sectional area than the outlets. Thus there is flow at less than sonic velocity in the conduit. Fitted within the bore 142 of body 140 is a sealing or bearing sleeve 148 having opposed diamond shaped ports 150, 152 through its peripheral wall that are in alignment with outlets 144, 146 respectively. Disposed within sleeve 148 is a cylindrical rotor 154 provided with a shaft 156 mounted by means of bearing 158 through seal 160 for rotation in valve body 140. Shaft 156 is driven at a constant speed by a motor (not shown) or other suitable driving means. The rotor 154 has a cylindrical cavity 162 opening toward flanged inlet conduit 132 and is provided with diamond shaped ports 164, 166, 168 through its peripheral wall 170 which are adapted for sequential registry with outlets 144, 146 as the rotor is driven whereby compressed air or other gas under pressure supplied through inlet 132 flows alternately through conduits 126, 128 as pulses 80 which vary with time in the manner illustrated in Fig. 10 and are discharged from slots 118, 120 for alternately and uniformly deflecting the filaments emerging from jet 112 (Fig. 7) The rotor 154 has a diameter, d, which is approximately the same as the internal diameter of sleeve 148, thereby providing a wiping contact between the rotor and sleeve as the rotor is driven. Outlet ports 150, 152 as well as rotor ports 164, 166, 168 have the same circumferential diagonal dimension *c*. The diagonal dimension of the ports which is in axial alignment with the valve body

(a, Fig. 8) may be from 0.75 to 1.25 the circumferential diagonal dimension *c*.

Normally the initial and final pressures of each pulse will be atmospheric pressure but may be more or less than atmospheric pressure. Normal operation at 6 to 100 pulses/second and an input pressure of 10 to 100 psi (0.7—7 Kg/cm^2) is contemplated. In order for the desired pressure pulse to be formed, in use, it is important that there be a sufficiently high pressure drop across the ports. This pressure drop should normally be 10 to 60 psi (0.7—4.2 Kg/cm^2) to deliver the desired pressure pulse. Pressure drop is determined by the port cross-sectional area. The key factor in designing a pulse shaping rotary valve and conduit is to develop flow at sonic velocity across the port at all degrees of openness and flow at less than sonic velocity in the exit conduit at all degree of openness. This is achieved if $\frac{\text{P drop}}{\text{P input}} >$ 0.37 when the port is fully open where P drop is the pressure drop across the port and P input is the input pressure (absolute) both measured in the same units and the conduit cross section is larger than the port cross section when fully open.

Port sizing for the required flow rate can be obtained by standard compressible fluid flow calculations as for example those obtained from "Fluid Density Calculator and Fluid Flow/Density Handbook" prepared by Missile Valve Division of Calmec Manufacturing Corporation.

Rotor and outlet ports should be identical in cross-sectional dimensions and match in the open position. When it is desired to provide pulses of gas at one outlet port at a time and to have at least one outlet producing a pulse at all times, the ratio circumferential diagonal dimension of a port to rotor diameter can be calculated from the formula

$$\frac{c}{d} = \sin \frac{\pi}{2n_r n_o} \text{ radians}$$

where *c* is the circumferential diagonal dimension of a port, *d* is the rotor diameter, n_r is the number of rotor ports and n_o is the number of outlet ports and is one or two. When $n_o = 1$, n_r can be any whole number. When $n_o = 2$, n_r can be any odd number.

The valve may be constructed from any material of suitable strength and durability. It is preferred that the rotor and valve body be constructed of mild steel and that the valve sleeve be constructed of bronze. Bearing type, number and disposition may be varied as required by the conditions of use.

Further, the conduit should be large enough to give sufficient damping of the gas so that the pressure of the gas decreases and increases in a manner directly proportional to time but not so large that there is an unduly large amount of fluid in the conduit and that reversal of the gas stream takes a significant amount of time.

In normal use the valve should have an increase in open area varying with $(\text{time})^n$ where n = 1 or more and is preferably 2. When n is less than 1, the time for reversal of the gas stream becomes significant and the pressure-time relationship of the pulse nearly parabolic.

The preferred filaments for use in this invention comprise isotactic polypropylene filaments segmentally drawn along the length of the fibers by passage over three unheated rolls followed by passage over a steam heated roll such as that described in British Patent Specification No. 1,099,000. The latter has a radially slotted surface to heat 7 inch (17.8 cm.) segments of the filaments with one inch separations. The filaments are then passed over unheated draw rolls. The continuous filaments thus formed are given a negative electrostatic charge by passing the ribbon of filaments across the target bar of a corona charging device such as that described in U.S. Patent Specification No. 3,163,753. Stripping of the ribbon of filaments from the draw roll is accomplished by the slot jet shown in Figure 2 which is similar to the slot jets described in U.S. Patent Specification No. 3,302,237, modified with a housing providing filament deflection gaps (discharge slots) which are supplied alternately with compressed air from the chamber as hereinbefore discussed. A useful compromise between efficiency and avoidance of the coanda effect is to align the discharge slot such that it makes an angle of 70° to the forward direction of the primary gas stream. The discharge slot should be sized to achieve the desired deflection at a moderate chamber pressure and air flow rate. The configuration of the jet exit and deflection gaps (discharge slots) also influence deflection efficiency. For example, notching the jet exit improves deflection efficiency. Design of this type of main jet-control jet interaction zone is known in the art, and has been published as in Department of Defence Report AD611189, "Study of Incompressible Turbulent Bounded Jets" by J. F. Foss and J. B. Jones.

For the preparation of wide nonwoven webs with filaments aligned in preferred directions, the output of many jets may be blended to form a nonwoven web of uniform fabric weight. The jets may be conveniently arranged in banks with the output of the jets in each bank being deflected in the same direction or the output of the jets in each bank can be deflected in different

directions (interleaving) so long as the deflected air streams do not interfere one with the other. Several banks of jets may be used to prepare the nonwoven webs, e.g., two, three, four or more banks of jets may be used.

In practice, manifolds may split the main air pulse into individual pulses which simultaneously enter designated chambers. Thus, when desired, designated gaps (discharge slots) providing air for deflection in a single direction receive pulses at the same instant and thus deflect in phase. Valves may be used to balance chamber pressures from jet to jet in a bank so that each jet deflects the threadline to the same angle. Air for secondary streams may be supplied to the chambers at a maximum pressure of from about 0.5 to about 50 psig. (.035—3.52 kg./cm.^{2}) but preferably not exceeding about 5 psig. (.35 kg./cm.^{2}). The filament forwarding jet 2 is normally operated with air at a pressure greater than 20 psig. (1.4 kg./cm.^{2}). The deflection gaps 5 and 6 may vary from .005 to .080 inch in width (.0127 to .203 cm.) but are preferably .015 to .020 inches (.038 to .051 cm.) wide. The deflection gaps 5 and 6 are preferably spaced from 0.1 to 0.2 inches (.25 to 0.51 cm.) from exit 4 of the slot jet 2 and extend the length of the exit 4. The slot jet exit 4, is spaced from 5 to 36 inches (12.7 to 91.5 cm.) preferably about 24 inches (61 cm.) above a receiving surface provided with suction means.

Filament speeds employed in the process of this invention usually range from 200 to 1800 yards per min. (183 to 1645 m./min.) or greater and the receiving surface usually has a speed of from 6 to 150 yards per min. (5.48 to 137 m./min) or greater. At a deflection frequency greater than 6.7 cycles/second and a maximum deflection amplitude of 24 inches, the deflection velocity is equal to the filament velocity (535 yards per min.) (489 m./min.). Further increases in the filament deflection frequency produce no further increase in deflection velocity since this is now controlled by the velocity of the filament immediately before oscillation. Under these conditions high deflection frequencies produce shorter deflection amplitude.

The Melt Flow Rate (MFR) of the resin used in the examples was measured by the procedure of ASTM-D 1238-62T using a load of 2,160 gm. and a temperature of 230°C. The MFR = weight in grams extruded over a period of 10 minutes.

The width loss or "neckdown" under longitudinal tensile stress of tufted nonwoven fabrics may be measured in the following manner: A tufted nonwoven fabric is cut into a sample 5.5 inches (14 cm.) wide (cross-machine direction, across tufting rows) and 14 inches (35.6 cm.) long (machine direction, along tufting rows). The sample is marked in the width direction with lines 4.0 inches (10.2 cm.) and 8.0 inches (20.3 cm.) from one end and 2.0 inches (5.1 cm.) from the other end. Metal staples are placed on the 8.0 inch (20.3 cm.) line 0.197 inch (0.5 cm.) from each edge of the sample. The distance between the staples is measured to the nearest 0.01 inch (.0254 cm.) and recorded. The sample is mounted in 1 inch (2.54 cm.) by 8 inch (20.3 cm.) "Instron" clamps so that the clamps are to and touching the 4.0 inch (10.2 cm.) and 2.0 inch (5.1 cm.) lines on the sample and the sample is centered in the clamps. ("Instron" is a Registered Trade Mark). The sample is mounted in an "Instron" tester with a clamp separation of 8 inches (20.3 cm.). The sample is extended using a full scale range of 50 lbs. (22.7 kg.), a cross-head speed of 10 inches (25.4 cm.) per minute and a chart speed of 20 inches (50.8 cm.) per minute. The "Instron" is set to stop when the total load reaches 18 lbs. (8.17 kg.) 3.3 lbs. (1.5 kg.) per inch of sample width) normally the load will overshoot to about 20 lbs. (9.08 kg.). The "Instron" is started. When the "Instron" stops, the distance between the staples is measured to the nearest 0.01 inch (0.0254 cm.) while the sample is still under stress. The percent neckdown is equal to the difference between the original distance between the staples and the distance between staples while under stress divided by the original distance between staples and multiplied by 100.

The machine direction "tongue tear strength" of a tufted nonwoven fabric may be measured in the following manner. A tufted nonwoven fabric is cut into a sample 6 inches (15.2 cm.) wide (cross-machine direction, across tufting rows) and 8 inches (20.3 cm.) long (machine direction, along tufting rows). The sample is cut in the center of the width 4 inches (10.2 cm.) in the machine (tufting) direction. The sample is mounted in an "Instron" tester using 1.5 inch (3.7 cm.) by 2 inch (5.1 cm.) serrated clamps. With a jaw separation of 3 inches (7.6 cm.), one side of the sample cut is mounted in the upper jaw and the other side of the sample cut is mounted in the lower jaw. The sample is uniformly spaced between the jaws. The full scale range is adjusted to a value greater than the tear strength expected for the sample. Using a crosshead speed of 12 inches (30.5 cm.) per minute and a chart speed of 10 inches (25.4 cm.) per minute, the "Instron" is started and the sample is torn. An average of the three highest stresses (one hundred units = full scale deflection) during tearing is taken. The tongue tear strength in pounds is the

average highest stress divided by 100 and multiplied by the full scale range.

The "tufted grab tensile" of a nonwoven fabric may be measured in the following manner. A tufted sample is cut into samples 4 inches (10.2 cm.) wide by 6 inches (15.2 cm.) long in the testing direction. The sampel is mounted in an "Intron" using a 1 inch (2.54 cm.) by 2 inch (5.08 cm.) clamp on the back side and a 1 inch (2.54 cm.) square clamp in the front side at a jaw separation of 3 inches (7.6 cm.). A cross-head speed of 12 inches (30.48 cm.) per minute is used. The peak of the "Instron" curve is read and reported as pounds breaking strength.

The distance between filament reversals (deflection amplitude) can be estimated by simple observation of the oscillating filaments, or by taking high speed motion pictures of the filaments.

Filament alignment can be determined by comparing the relative proportion of the filaments aligned in one direction with that in another direction throughout the sheet. This comparison has the advantage that it is universally applicable to straight, curved, or crimped fibers. In a random sheet, the proportion of filaments aligned in any one orientation is the same as at any other orientation.

The randometer method is based on the principle that only the incident light rays which are perpendicular to the axis of a filament are reflected as light rays which are perpendicular to the filament axis. Hence, by focusing a beam of parallel light rays on a nonwoven sheet at an incident angle less than 90°, e.g., 60°, the light which is emitted perpendicular to the plane of the sheet comes only from filaments having an orientation within the plane of the sheet which is perpendicular to the incident light rays. By collecting, measuring photoelectrically and comparing the intensity of the light obtained using different incident angles, e.g. by rotating the sheet, the proportions of filaments oriented perpendicular to the light rays, therefore, parallel to each other, can be determined for each incident angle. Thus an analysis of filament alignment can be made.

An apparatus suitable for this measurement is shown schematically in Figure 6 and will hereinafter be referred to as a randometer. A detailed description of the components, the method of operation, and the method for standardizing the characterizations are given below.

As shown in Figure 6, the apparatus has a revolving stage 46 on which the sample 47 to be examined is placed. Stage 46 is modified by gear 48 which has half the teeth removed so that when driven by synchronous motor 49, it rotates through only 180°. Stage 46 rotates at 1/4 rpm, thus the time for rotation of the sample through 180° is 2 minutes. Lamp 50 is located directly over the sample and in line with magnifying lens system 51. Lamp 50 is a 6-volt lamp and its intensity is controlled through 6-volt transformer 52 and variable-voltage transformer 53. The light from 50 is focused by lens 51 onto the bottom of the sample, and when projected through objective lens 54, eyepiece 55 and reflected from mirror 56, gives a shadow of the sample on ground-glass screen 57 at a magnification of 36X. Screen 57 is circular and has a diameter of 6.9 inches (17.5 cm.).

A second lamp 58 is mounted in a housing with projection lens 59 to focus the light on the sample at an angle of 60°. Lamp 58 is a 25-watt, concentrated arc lamp receiving its power from power supply 61 which is modified to eliminate the A.C. ripple. The filaments or segments of filaments which are perpendicular to the light from lamp 58 reflect the light into the magnifying lens and mirror system to screen 57 for measurement. Optical slit 62 is located between the objective lens 54 and stage 46 and serves to control the limits of the light reflected from the sample. The slit is 1/16 in. × 3/8 in. (.159 cm. × .954 cm.) and is mounted with its long axis parallel to an imaginary line which is perpendicular to the light from lamp 58 and within the plane of the sample.

The light from the screen is focused by Fresnel lens 63 onto photomultiplier tube 64 (RCA type 1P21) having a 2500 volt DC power supply 65. The screen, Fresnel lens, and photomultiplier tube are contained in a single light tight unit, which can, however, by opened for visual observation of the screen. The output from the photomultiplier tube is fed into a microampere recorder 66 having a chart speed of 8 in./min. (20.3 cm./min.) and a chart 9.5 in. wide (24.2 cm.). The chart records the light reflected from the parallel filaments at each direction as the sample is rotated through 180°. The sensitivity of recorder 66 should be adjusted so that a current of 6 microamperes gives 100% pen deflection.

A two-way switch 67 is in the line from the photomultiplier tube to the recorder so that the signal can be measured on a sensitive microampere meter 68, if desired. This meter can also be used in conjunction with a 6-volt lamp of fixed intensity to measure the fiber density of the sample so that, if desirable, all samples can be compared on the same basis.

Samples of the nonwoven sheet to be examined should permit clear viewing on the randometer of all the filaments through the thickness of the samples. Samples in excess of 1.9 oz. yd.^{2} (64.2 g./m^2) should

be delaminated to layers having a weight of 0.75—2.0 oz./yd.^{2} (25.4—67.5 g./m.^{2}), but care should be exercised to avoid disturbing the filament alignment during delamination.

The delaminated samples are placed between two microscope slides which are then taped together. The slide is placed on the revolving stage so that the light from lamp 58 shows on the sample. The background lamp 50 is then turned on and the filaments are focosed as sharply as possible by moving revolving stage 46 up or down, while they are viewed on the screen. Lamp 50 is then turned off. Stage 46, lamp 58 and projection lens 59 are enclosed in a light tight unit. The voltage of power supply 65 is adjusted so that the pen will remain on scale in the directions of maximum filament alignment and the intensity of the reflected flight is recorded on the microampere recorder chart as the sample is rotated through 180°.

The heights of the intensity-orientation curve so obtained are measured in inches from the zero line of the chart at 80 equally spaced orientations and the arithmetic mean of these heights is determined. To standardize the randometer characterization, each of the 80 readings is multiplied by the factor $\frac{5}{\text{arithmetic mean}}$, to shift the curve to a standard mean (5 in. pen deflection). When obtaining measurements on nonwoven webs with preferentially oriented filaments, the samples are delaminated into layers having fabric weights between 0.75 and 2.0 oz./yd.^{2} (25.4—67.5 g./m.^{2}) and measurements are taken on each layer. To improve the precision several measurements may be made on each layer. For each layer, the standardized readings at each angle are averaged to obtain a curve for that layer. Then a curve for the entire sample is constructed by averaging the readings at each angle for the different layers in proportion to the fabric weight of these layers. This method was used to obtain the data plotted in Figures 4 and 5.

A measure of the alignment of the filaments in a non-woven web in a given direction can be expressed as the percentage of the area under a curve, corresponding to the curves of Figures 4 and 5, and within ± 9° of the given direction, to the total area under the curve. Further details of the treatment and analysis of the randometer results are given in our copending Application No. 63602/69 (Serial No. 1,244,754).

The following Example further illustrates the invention.

In this Example, the valve used had three diamond-shaped ports, 1.1 inches in the circumferential direction and 1.1 inches in the axial direction with a rotor diameter of 4.5 inches. The pulses travelled through conduits a distance of about 14.5 ft. to each deflection chamber, the length of all the conduits being the same.

The conduits were sized so there would be a pressure drop of about 25 psi. and a constant flow at less than sonic velocity at a rate of 60 scfm. per chamber (essentially the peak flow rate). The air pressure at the valve connected to the cross-machine direction deflecting jets was 50 psig. and that to the machine direction deflecting jets 40 psig. Total laydown width was about 182 inches and about 6 inches were trimmed from each edge.

EXAMPLE

A nonwoven web is produced using an arrangement similar to that illustrated in Figure 1 except that a first bank of 14 slot jets (12 7/8 inches apart, center to center) are used for machine direction deflection substantially along the axis in which the receiving surface moves away from the laydown zone and a second bank (about 7 ft. from the first bank) of 14 slot jets (12 7/8 inches apart, center to center,) are used for cross machine direction deflection (substantially at right angles to machine direction deflection). Each jet has a 6 inch wide inlet and a 9.31 inch wide diffuser. Polypropylene filaments (500 filaments at each position) are spun from 8.5 MFR polymer and segmentally drawn along their length by passage successively over three unheated feed rolls operating at peripheral speeds of 187, 195 and 207 yards per min. (171, 178 and 189 m./min.) and then over a heated roll of the type disclosed in British Patent Specification No. 1,099,000 operating at a peripheral speed of 216 yards perm in. (197 m./min.) and heated at 130°C. but adapted with an axially slotted surface to heat seven inch (17.8 cm.) segments of the filaments with one inch (2.54 cm.) separations and then passed over two draw rolls operating at 653 yards per min. (596 m./min.). The continuous filaments thus formed are given a negative electrostatic charge by passage across the target bars of corona charging devices such as those described in U.S. Patent Specification No. 3,163,753. Continuous filaments are removed from the draw rolls by slot jets of the type shown in Figure 2 using a jet chamber pressure of 24 psig. (1689 g./cm.^{2}) in the jets aligned for machine direction deflection and a jet chamber pressure of 20 psig. (1407 g/cm^2) in the jets aligned for deflection in the cross machine direction. The output of the first bank of jets is deflected a total distance (deflection amplitude) of 20 inches (50.8 cm.) at a deflection frequency of 4.5 cycles/sec. using a peak deflection chamber pressure of 1 psig. (70.3 g/cm^2).

The output of the second bank of jets is laterally deflected a total distance (deflec-

tion amplitude) of 26 inches (66 cm.) at a deflection frequency of 4.5 cycles/sec. using a peak deflection chamber pressure of 2 psig. (140.6 g./cm²). The nonwoven web is collected on a moving receiving surface having suction means at 14.9 yards per min. (13.6 m./min.) and bonded in saturated steam at 90 psig. (6.3 kg./cm.²). A nonwoven fabric with a fabric weight of 3.5 oz./yd.² (128.5 g./m.²) is obtained.

Filament alignment of this bonded nonwoven fabric determined by the "randometer" method gave an MD of 15.0% an XD of 9.9% and a 45° of 8.35%.

The bonded nonwoven fabric is immersed in a 4% aqueous dispersion of a polysiloxane which contains 0.4% of a surface active agent (sodium alkylarylsulfonate). The fabric is then squeezed between two rolls at a speed of 1.5 yd./min. (1.4 m./min.) and dried in a circulating air oven at 93°C. for 45 minutes. About 2% by weight polysiloxane is added by this treatment. The fabric is tufted under the following conditions:

Type of Machine Gauge (distance between needles)	0.188 in. (0.48 cm.)
Speed	400 tufts/min., 7 tufts/in. (2.8 tufts/cm.)
Pile Yarn (nylon carpet yarn) ...	3700 denier (410 tex) continuous filament
Tuft Height	0.438 in. (1.11 cm.)
Type Pile	loop

After tufting, the nonwoven fabric has a machine direction tongue tear strength of 29 lbs. (13.2 kg.) and a cross machine direction grab tensile strength of 78 lbs. (35.4 kg.). On loading 3.3 lbs. per inch (0.589 kg./cm.) in the machine direction the nonwoven fabric decrease in width 1.1%.

Further exemplification of the production of non-bonded fabrics in accordance with this invention is given in our copending Application No. 63602/69 (Serial No. 1,244,754).

In our copending Application No. 63602/69 we claim a continuous length as defined therein) of bonded non-woven fabric comprising continuous synthetic filaments which are disposed in the fabric in ordered manner such that:

(a) XD/45° is at least 1.2;
(b) MD/XD is between 0.25 and 1.5; and
(c) MD/45°+XD/45° is less than 6,

XD/45°, MD/45° and MD/XD being as defined in Application No. 63602/69, those of the said filaments lying in a direction generally transverse to the continuous fabric length direction proceeding for a distance of at least 7 inches in that first mentioned direction. That Application No. 63602/69 also claims a process for making such a bonded fabric which comprises forming a plurality of primary gas streams each forwarding a plurality of electrostatically charged continuous filaments and collecting the separated filaments from the gas streams on a continuously moving receiving surface, at least one of the gas streams being pneumatically oscillated so that its filaments traverse the receiving surface at a substantially constant deflection amplitude (as defined therein) of at least 7 inches and at a substantially constant deflection velocity (as defined therein) which is at least one-third the velocity of these filaments along their length, as measured immediately before oscillation; and bonding the fabric.

We make no claim to the subject matter claimed in our copending Application No. 63602/69 (Serial No. 1,244,754) in this specification.

Subject to the above disclaimer,
WHAT WE CLAIM IS:—

1. A process for preparing a unitary directional non-woven web by forming a plurality of primary gas streams each forwarding a plurality of electrostatically charged continuous filaments and collecting the separated filaments from the gas streams on a continuously moving receiving surface, in which process at least one of the gas streams is pneumatically oscillated so that its filaments traverse the receiving surface at a substantially constant deflection amplitude (as hereinbefore defined) and at a substantially constant deflection velocity (as hereinbefore defined) which is at least one-third the velocity of these filaments along their length, as measured immediately before oscillation.

2. A process according to claim 1 wherein the electrostatically charged filaments are charged to at least 30,000 ESU/m².

3. A process according to claim 1 or 2

wherein the filaments which are forwarded are composed of isotactic polypropylene.

4. A process according to any one of claims 1—3 wherein the oscillation is effected by periodically impinging on the primary gas stream at least one secondary gas stream whose forward direction makes an angle of 60—90° to the forward direction of the primary gas stream such that the filaments forwarded by the primary gas stream are deflected by not more than 45°.

5. A process according to any one of the preceding claims wherein the oscillation is in a direction at an angle of 45—90° to the direction of travel of the receiving surface.

6. A process according to claim 5 wherein the angle is 90°.

7. A process according to any one of the preceding claims wherein a plurality of the primary streams are oscillated simultaneously in the same direction and the group of filaments collected from each of the primary gas streams of this plurality contact the or each group of filaments collected from the or each adjacent primary gas stream of this plurality.

8. A process according to claim 7 wherein contact occurs at least at the points in the groups of collected filaments where the filaments reverse direction.

9. A process according to claim 7 or 8 wherein there is simultaneously a first and a second such plurality of primary gas streams forwarding filaments, the direction in which the first plurality is oscillated being at right angles to the direction in which the second plurality is oscillated.

10. A process according to claim 9 wherein one of the directions of oscillation is the direction of travel of the receiving surface and the other is at right angles to this.

11. A process according to claim 10 wherein the group of filaments collected from each primary gas stream of the plurality being oscillated at right angles to the direction of travel of the receiving surface contacts the or each group of filaments collected from the or each adjacent primary gas stream of this plurality at least at the points in the groups where the filaments reverse direction, and the group of filaments collected from each primary gas stream of the plurality being oscillated in the direction of travel of the receiving surface contact the or each group of filaments collected from the or each adjacent primary gas stream of this second plurality at least along the edges of the groups of filaments.

12. A process according to any one of claims 7—11 wherein the gas streams in each of the pluralities of primary gas streams are parallel to each other immediately before oscillation and are oscillated in phase with each other.

13. A process according to any one of the preceding claims wherein the plurality of filaments forwarded by at least one of the gas streams is in the form of a ribbon of filaments.

14. A process for preparing a unitary non-woven web, performed substantially as hereinbefore described.

15. A process for preparing a unitary non-woven web, performed substantially as hereinbefore described in the Example.

16. Apparatus suitable for carrying out a process claimed in claim 1, comprising

(a) a plurality of filament-forwarding devices, each device being adapted to forward a plurality of electrostatically charged filaments in a primary gas stream, at least one of the devices containing a passageway whose principal axis is a straight line and whose cross-section perpendicular to this axis is a rectangle, down which passageway the gas stream and filaments pass,

(b) a means at the bottom of said passageway for pneumatically oscillating the primary gas stream emanating from said passageway, the means comprising at least one slot whose length is parallel to the length of said rectangle, which slot is connected to a source of gas under pressure, the means being adapted to supply pulses of that gas from a chamber through the slot as a secondary gas stream to impinge on the primary gas stream emanating from said passageway such that the forward direction of the secondary gas stream makes an angle of 60—90° to the forward direction of the primary gas stream,

(c) a continuously moving receiving surface adapted to collect the separated filaments from the gas streams.

17. Apparatus according to claim 16 wherein the pressure of the secondary gas stream in the chamber increases and decreases in a manner substantially directly proportionally to time.

18. Apparatus according to claim 16 or 17 wherein the slot in means (b) is of width 0.005—0.080 inch.

19. Apparatus according to any one of claims 16—18 wherein the angle referred to under (b) is 70°.

20. Apparatus according to any one of claims 16—19 wherein in means (b) there is a pair of said slots aligned on opposite sides of said passageway such that the pulses of secondary gas supplied through the slots impinge on the principal axis of the passageway at the same point, both slots being connected to the same source of gas

under pressure *via* a valve adapted to supply pulses of the gas alternately to the slots.

21. Apparatus according to any one of claim 16—20 wherein in means (b) the slot is connected to the source of gas under pressure *via* a valve and a conduit from the valve to the chamber, the valve comprising:

(a) a valve body with a cylindrical bore defining a peripheral wall, an inlet at one end of the body adapted to connect to the source of gas and at least one outlet in the peripheral wall connected to the conduit; and

(b) a driven cylindrical rotor disposed in wiping contact in the bore, there being a cavity in the rotor in communication with the inlet and a peripheral rotor port in communication with the cavity and adapted for full registry with the outlet, thereby providing periodic communication between the outlet and the inlet during rotation of the rotor; the port, during registry with the outlet, providing a change in the open area, Z, of the outlet which varies with time, t, such that, Z is proportional to t^n, where n is 1 or greater, during the period from the beginning of registry to full registry of the port and outlet, the valve being sized to provide flow at sonic velocity through the outlet at all degrees of correspondence of the outlet and port during registry, and the conduit being sized to provide flow at less than sonic velocity at all degrees of openness of the valve and such that the pressure in the chamber increases and decreases in a manner substantially directly proportional to time.

22. Apparatus according to claim 21 wherein between the rotor and the peripheral wall of the valve body there is a bearing sleeve coaxial with the bore of the valve body and having a port in alignment with the or each outlet in the peripheral wall.

23. Apparatus according to claim 21 or 22 wherein the rotor port is in the shape of a square, diamond, triangle or hypocycloid.

24. Apparatus according to claim 23 wherein the apices of the rotor port are symmetrically aligned with respect to the rotor axis.

25. Apparatus according to any one of claims 21—24 wherein n is substantially 2.

26. Apparatus according to claim 16 which is substantially as hereinbefore described.

27. Apparatus according to claim 16 which is substantially as described with reference to and as illustrated in Figure 1.

28. Apparatus according to claim 16 wherein the means (b) and the device containing the passageway are substantially as described with reference to and as illustrated in Figures 2 and 3.

29. Apparatus according to claim 21 wherein the valve and conduit are substantially as described with reference to and as illustrated in Figures 7, 8 and 9.

30. Process according to claim 1 which is carried out in apparatus claimed in any one of claims 16 to 29.

31. A non-woven web prepared by a process claimed in any one of claims 1—14 and 30.

32. A non-woven web according to claim 31 which has been bonded.

33. A non-woven web according to claim 32 which after being bonded has been tufted.

34. A process according to claim 1 wherein the filament velocity is at least 200 yards per minute.

35. A process according to claim 34 wherein the filaments which are forwarded are composed of isotactic polypropylene.

36. A process according to claim 34 or 35 wherein a plurality of the primary gas streams are oscillated simultaneously in the same direction and the group of filaments collected from each of the primary gas streams of this plurality contact the or each group of filaments collected from the or each adjacent primary gas stream of this plurality.

37. A process according to claim 36 wherein contact occurs at least at the points in the groups of collected filaments where the filaments reverse direction.

38. A process according to claim 36 or 37 wherein there is simultaneously a first and a second such plurality of primary gas streams forwarding filaments, the direction in which the first plurality is oscillated being at right angles to the direction in which the second plurality is oscillated.

39. A process according to claim 38 wherein one of the directions of oscillation is the direction of travel of the receiving surface and the other is at right angles to this.

40. A process according to claim 39 wherein the group of filaments collected from each primary gas stream of the plurality being oscillated at right angles to the direction of travel of the receiving surface contacts the or each group of filaments collected from the or each adjacent primary gas stream of this plurality at least at the points in the groups where the filaments reverse direction, and the group of filaments collected from each primary gas stream of the plurality being oscillated in the direction of travel of the receiving surface contact the or each group of filaments collected from the or each adjacent primary gas stream of this second plurality at least along the edges of the groups of filaments.

41. A non-woven web prepared by a pro-

cess claimed in any one of claims 15 and 34 to 40.

42. A non-woven web according to claim 41 which has been bonded.

43. A non-woven web according to claim 42 which after being bonded has been tufted.

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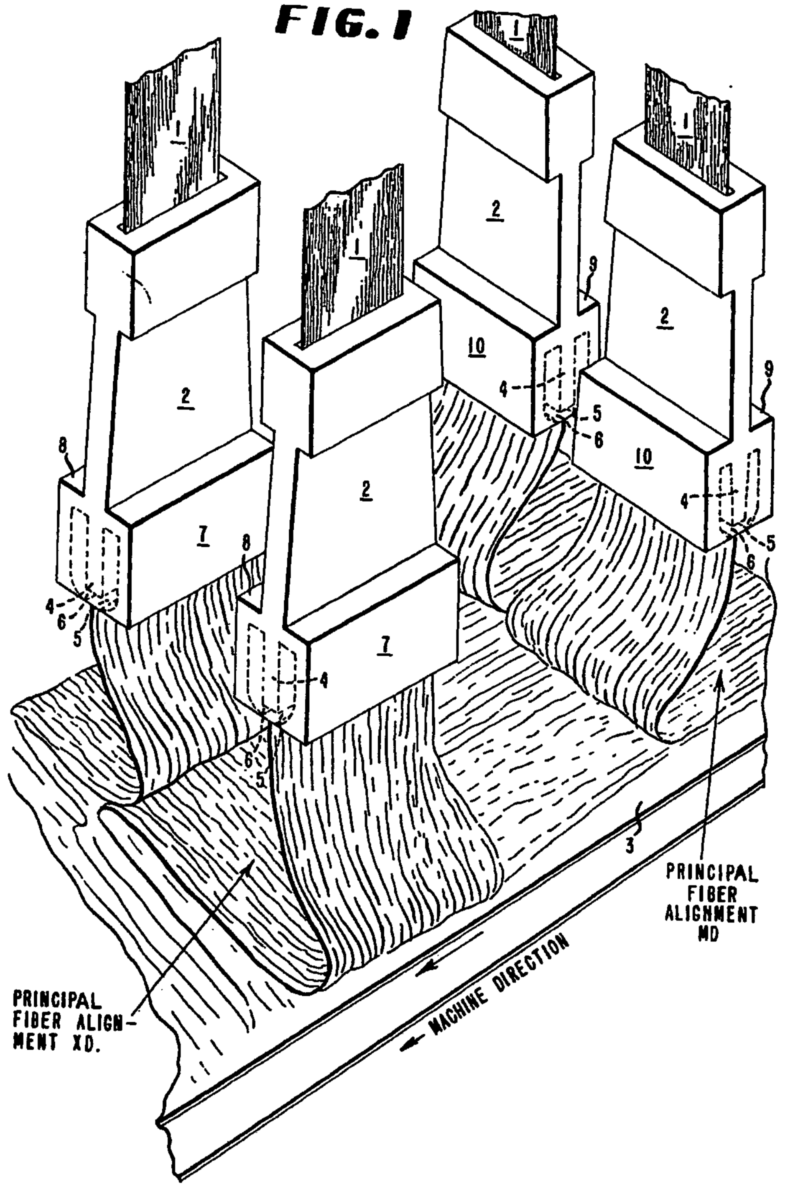
FIG. 1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2
7
8
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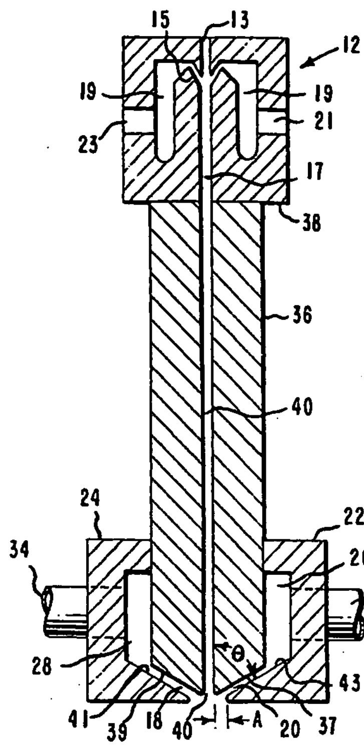
4
5
6
3
PRINCIPAL FIBER ALIGNMENT MD
PRINCIPAL FIBER ALIGNMENT XD.
MACHINE DIRECTION

FIG. 2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21
23
17
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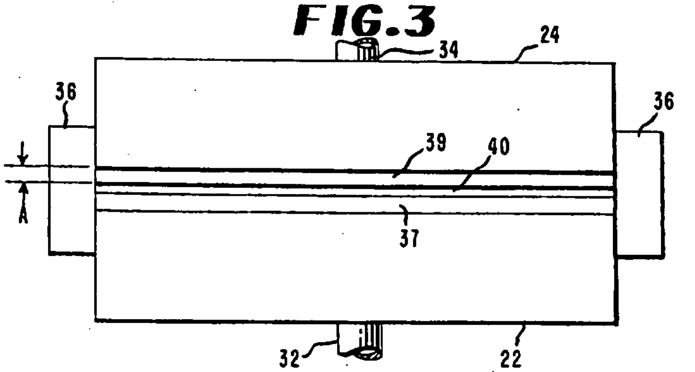
18
40
A
20
37

FIG. 3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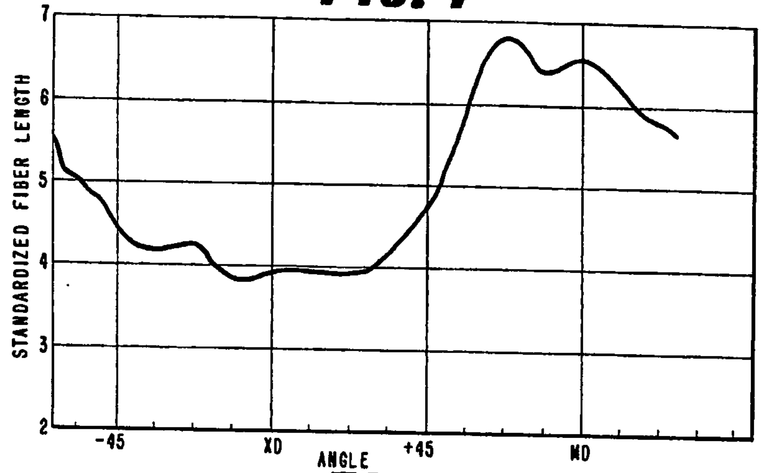
32
22

FIG. 4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MD
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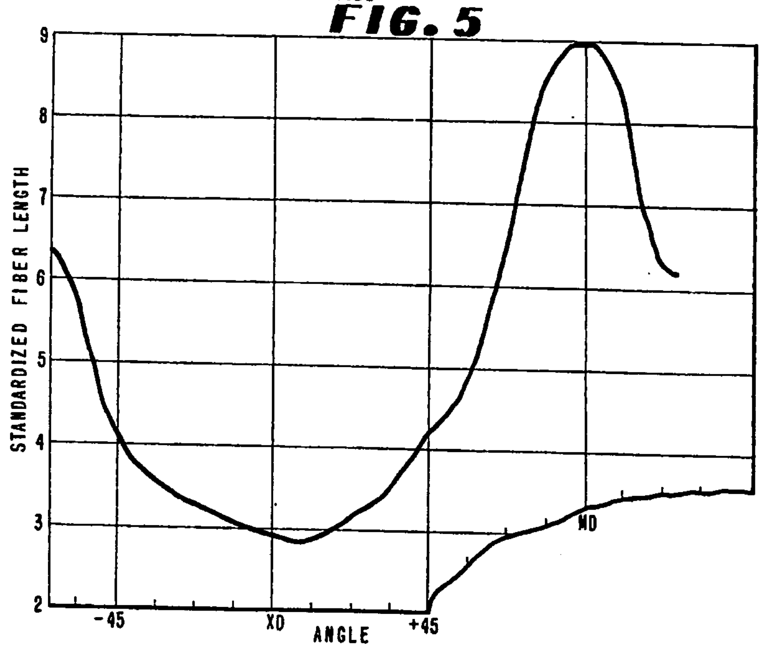
FIG. 5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XD
+45
MD
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1244753 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 4

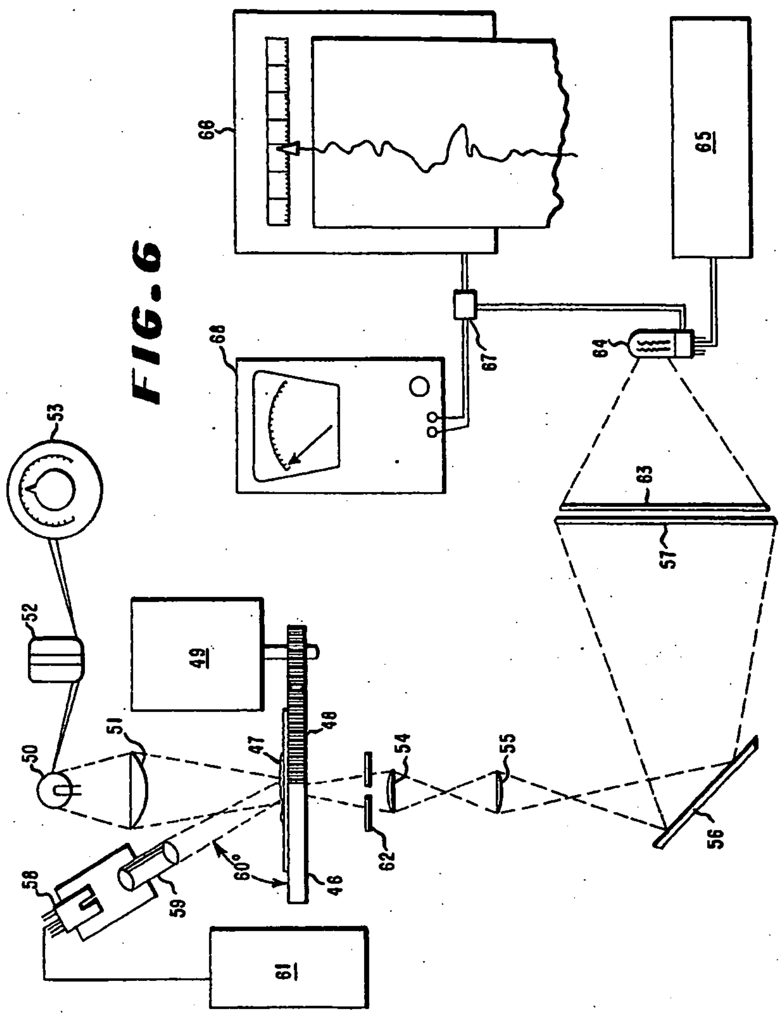
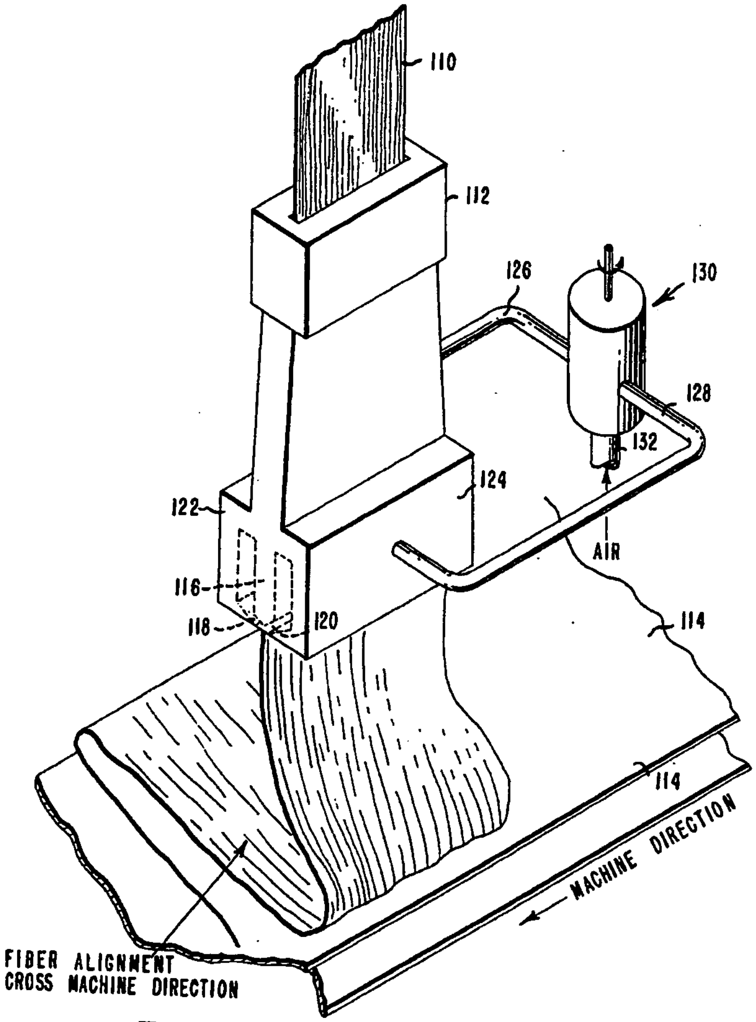


FIG. 6

FIG. 7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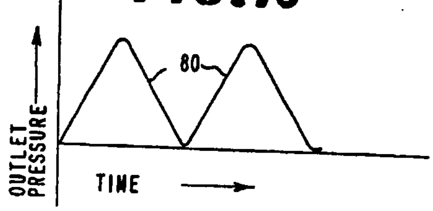
MACHINE DIRECTION
FIBER ALIGNMENT
CROSS MACHINE DIRECTION

FIG. 10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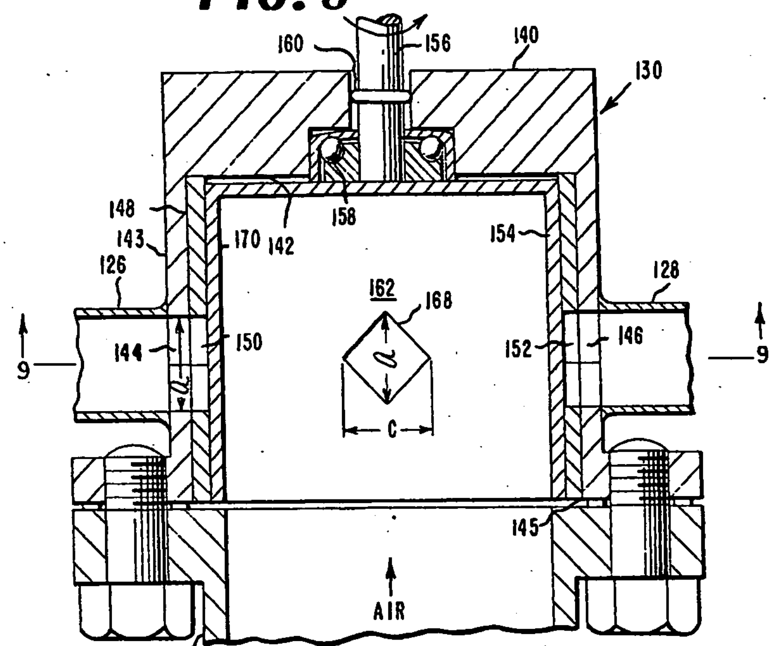
OUTLET PRESSURE
TIME

FIG. 8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AIR
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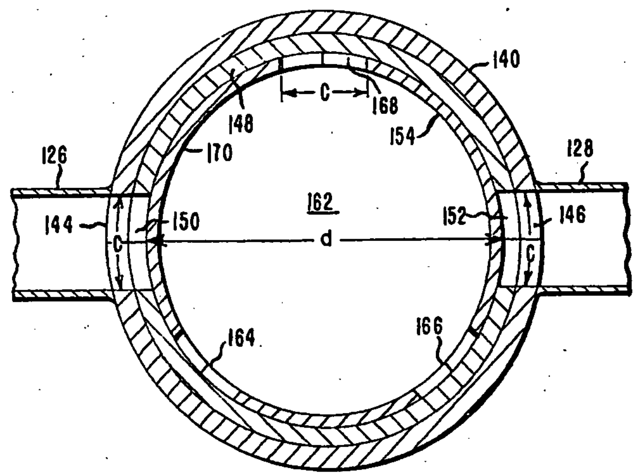
FIG. 9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150
152
146
C
d
C
164
166